

## High time resolution observations of a Vela glitch

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**Abstract.** Pulsars are rotating neutron stars, sweeping the emission regions from the magnetic poles across our line of sight. Isolated neutron stars lose angular momentum through dipole radiation and (possibly) particle winds, hence they slow down extremely steadily, making them amongst the most reliable timing sources available. However, it is well known that younger pulsars can suffer glitches, when they suddenly deviate from their stable rotation period. On 2000 January 16 (MJD 51559) the rate of pulsation from the Vela pulsar (B0833-45) showed such a fractional period change of  $3.1 \times 10^{-6}$ , the largest recorded for this pulsar. The glitch was detected and reported by the Hobart radio telescope. The speedy announcement allowed the X-ray telescope, Chandra, and others, to make Target of Opportunity observations. The data placed an upper limit of 40 seconds for the transition time from the original to the new period. Four relaxation timescales are found, which are believed to be due to the transfer of inertia through the internal structure. One is very short, about 60 seconds; the others have been previously reported and are 0.56, 3.33 and 19.1 days in length.

### 1. Introduction

Observations of pulsar glitches, in addition to providing insights into the phenomenon itself, offer one of the few probes of neutron star structure, and thus the physics of ultra-dense matter. Vela is the brightest known radio pulsar, and as it is at a declination of  $-45^\circ$ , it is above the horizon at the Hobart Radio Observatory (Mount Pleasant) for more than 18 hours a day. It undergoes large glitches in pulse rate every few years and so provides an excellent test-bed for the neutron star equations of state.

Since 1981 the University of Tasmania has devoted a 14m diameter antenna at its Mt Pleasant Observatory to measurements of arrival times of pulses from the Vela pulsar. During this time we have observed 7 large glitches, or sudden decreases, in the period of the pulsar (McCulloch et al 1983, McCulloch et al 1987, McCulloch et al 1990, McCulloch 1996)

The telescope has a single pulse observing system whose speed and sensitivity have been enhanced in order to answer a number of questions; how quickly does the crust accelerate to the new period during a glitch, how soon does the recovery from the glitch start, and what is the form of this recovery?

On 2000 January 16 (MJD 51559) the rate of pulsation jumped with a fractional period change of  $3.1 \times 10^{-6}$ , the largest recorded for this pulsar. The glitch

was automatically detected and we issued an IAU telegram (Dodson, McCulloch, & Costa 2000) within 12 hours, allowing the X-ray telescope, Chandra to make Target of Opportunity observations (Helfand, Gotthelf, & Halpern 2001). These observations have so far failed to find the signature of neutron star heating, which was the driver for the observations, but have produced spectacular images of the X-ray pulsar wind nebula.

## 2. Observations

The reported observations were made simultaneously at 635 MHz, 990 MHz and 1390 MHz, to allow continuous measurement of the dispersion measure (DM). The signal-to-noise ratio in each total intensity profile is typically 30:1, allowing a mean pulse arrival time to be determined to an accuracy of  $80\mu\text{s}$  at 635 MHz,  $60\mu\text{s}$  at 990 MHz and  $180\mu\text{s}$  at 1390 MHz per integration.

The recent improvements in the time resolution have been achieved by de-dispersing over 8 adjacent channels at 990 MHz, thereby increasing the signal to noise ratio and allowing observations of single pulses. The de-dispersed bandpass is sampled at 2 kHz and recorded directly onto disk for later retrieval, while an ‘on the fly’ monitoring system folds on a ten second basis for which the RMS is  $85\mu\text{s}$ . These arrival times are monitored and if a glitch is detected a warning is issued and the single pulse data are retained.

## 3. Timing fits

The data presented here were recorded between MJD 51505 and 51650. The arrival times have been transformed to the Solar System barycentre using standard techniques. The position and proper motion of the Vela pulsar was defined by data from the Radio VLBI position of Legge (Legge 2001).

The recorded TOAs from all frequencies and both systems were fitted in the program **TEMPO** (Taylor et al 1970). The results of this fit are given in Table 1.

Shortly after 07:34 UT, the residuals diverge from the fit, indicating a sudden decrease in pulse period. The period jump occurs on a very short timescale, without warning. The observations are consistent with an instantaneous change in period; modelling has shown that a spin-up timescale of forty seconds would produce a three sigma signal.

The separation into four time-scales is clear. The longer three decay terms are similar to those previously reported (Alpar et al 1993, Flanagan 1990), and are in an approximately equal ratio of 5.9:5.7. These have been associated with the vortex creep models by (Alpar et al 1993) and others. The fast decay timescale, not previously observed (or observable) is shown separated from the other effects in figure 1. We have subtracted the terms found by **TEMPO** in the 2 minute data from the single pulse data folded for 10 seconds. In this plot a gradual spin-up (as opposed to an instantaneous) would be a negative excursion around the projected time of the glitch, as we’d have overestimated the phase in the model. We see a positive excursion, indicating that the true glitch epoch was later, and is followed by a rapid decay. We have fitted a linear rise ( $\Delta\nu\Delta t$ ) followed by a fourth decay term to this.

#### 4. Future development

Since the acceleration of the crust cannot be instantaneous, it should be possible to observe the spin-up of the rotation period of the pulsar. The parallel single pulse system designed to observe this has a three  $\sigma$  detection limit of less than 40 seconds. This is in contrast to the observations made on the Crab (Wong, Backer, & Lyne 2001) where the spin-up timescale has been observed to take about  $\sim 0.5$  of a day. Further improvements of the single pulse system are being undertaken which will allow a detection limit of a few seconds, which is of the order of the fastest coupling times in all EOS models. Higher time resolution will allow further constraints on the coupling of the crust to the liquid interior, including the core.

Parameters for Epoch 51559		
$\nu/Hz$	$\dot{\nu}/Hz\ s^{-1}$	$\ddot{\nu}/Hz\ s^{-2}$
11.194615396005	-1.55615E-11	1.028E-21
$\Delta\nu_p/Hz$	$\Delta\dot{\nu}_p/Hz\ s^{-1}$	
3.45435(5)E-05	-1.0482(2)E-13	
$\tau_n$	$\Delta\nu_n/10^{-6}Hz$	
1.2 $\pm$ 0.2mins	0.020(5)	
00.53(3) days	0.31(2)	
03.29(3) days	0.193(2)	
19.07(2) days	0.2362(2)	
DM	67.99	

Table 1. Parameters for the glitch epoch 51559.3190. Errors are the one sigma values. The data fit is from MJD 51505 through to 51650 (November 1999 to April 2000).

#### References

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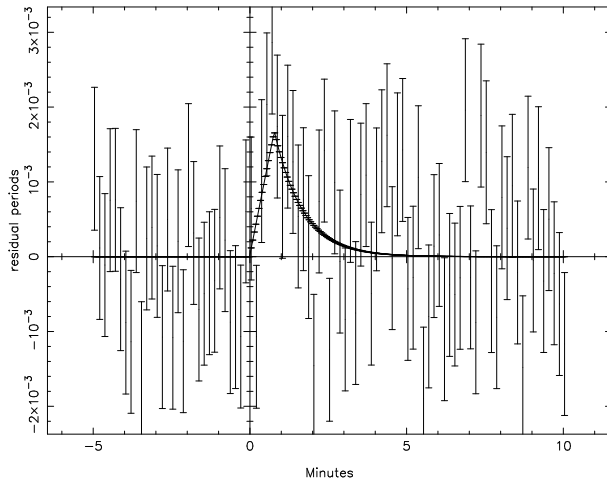


Figure 1. The previously unobserved fast decay, with ten second folds. The other decay terms are removed revealing the later start, and decay of the fastest term.

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